THE MECHANISM AND ITS INFLUENCE ON KARSTIC SPRINGS FLOW OF SARCHINAR SPRING, A CASE EXAMPLE, SULAIMANIYAH, NE IRAQ

Salahalddin S. Ali*, Zoran Stevanovic and Igor Jemcov****

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ABSTRACT

The Sarchinar spring is one of the largest springs in northern Iraq, it supplies municipal water for the Sulaimaniyah city of 700000 inhabitants. The outlet drains a large catchment area, some 200 Km^2 of the Sarchinar – Chaq Chaq karstic system.

The recharge of the spring is based on: **A)** the diffuse infiltration of rainfall through the exposed outcrops of Jurassic and Cretaceous (Qamchuqa – Kometan or Balambo formations, thickly-bedded and highly fractured limestone layers); **B)** the percolation of runoff and intermittent stream water of Chaq Chaq valley through tectonically active zones. During the recession periods of the extremely dry 1999 and 2000, the minimal discharge of the system was around 600 l/sec. The recorded maximum discharge during the period 1999 – 2005 was 7454 l/sec (March, 2003).

For the characterization of karstic aquifer and discharge regime evaluation, the analyses of input – output relationship was applied including the autocorrelation, cross-correlation and spectral density methods. The main characteristics are cyclic variations and significant aquifer storage capacity. During winter time, the system reacts to rainfall events with a delay of a few days representing the minimum travel time for the recharging inputs. Meanwhile, a slow reaction could be observed during low water period after approximately one month (rainfall at the beginning of May transferred as output at the beginning of June).

The regime of this spring is determined by several factors, the principals are: arid climate and unstable recharge (six months without rainfall), well karstified and fractured aquifer system, and recharge by seepage from the nearby Chaq Chaq valley.

ميكانيكية الجريان وتأثيراتها على العيون التكهفية، عين سرجنار، حالة نموذجية، السليمانية، شمال شرق ألعراق

صلاح الدين سعيد علي، زوران ستيفانوفيج و أيكور جيمكوف

المستخلص

يعتبر عين سرجنار، الذي يزّود مدينة السليمانية ذي 700000 نسمة بمياه الشرب، أحد أكبر العيون في شمال العراق. إن مساحة التغذية للنظام التكهفي للخزان، والتي تعرف بسرجنار- جق جق تقدر بحوالي 200 كم^2. تتأتى المصادر ألأساسية لتغذية العين من مصدرين هما: **أ)** ترشح مياه الأمطار والثلوج من خلال التشققات والكسور الموجودة في مكاشف الصخور الكاربوناتية المتطبقة للعمر الكريتاسى والجوراسى. **ب)** ترشح مياه السيول لوادي جق جق الموسمي من خلال الأنطقة التكتونية النشطة. إن التصريف الأقل لعين سرجنار والذي سجل في موسم الفتور للفترة 1999 - 2000 كان 600 لتر/ثانية، بينما سجلت أعلى قيمة تصريف في آذار 2003 وكانت 7454 لتر/ثانية.

* Department of Geology, College of Science, University of Sulaimaniyah, Iraqi Kurdistan Region, Iraq. e-mail: salahsulus@yahoo.com

** Department of Hydrogeology FMG, University of Belgrade, Djusina 7, Belgrade 11000, Serbia. e-mail: zstev@eunet.yu and jemcov@gmail.com

من أجل التعرف على سلوكية ونظام تصريف الخزان التكهفي وتقييمه، تم تحليل المعطيات الداخلة والخارجة والمتمثلة بكمية الأمطار اليومية بالمقارنة مع التصريف اليومي للعين. وكانت العلاقات متمثلة بالعلاقات الذاتية والعلاقات التقاطعية والكثافة الطيفية.

تبين ان القابلية الخزنية العالية والتغاير الدوري من أهم خواص عين سرجنار، حيث يتفاعل النظام مع الأمطار بتأخر لعدة أيام خلال موسم الشتاء، وهذا يمثل أقل زمن لانتقال المياه الداخلة الى النظام، في حين لوحظ تفاعلاً بطيئاً عند فترات مواسم الجفاف، حيث تصل فترة الاستجابة الى شهراً واحداً.

تشارك عدة عوامل في تأثيرها على نظام الجريان في خزان هذه العين، أهمها المناخ الجاف والتغذية غير المستقرة (بسبب انقطاع الأمطار لمدة ستة أشهر) ونظام عالي التشقق والتكهف للخزان المائي، والعامل الآخر هو التغذية القادمة من تسرب مياه نهر جق جق الموسمي من خلال الأنطقة النشطة تكتونياً.

INTRODUCTION

Sarchinar spring is well known in the region by its very large discharge and great resort area formed around the spring. It is locally considered as one of the natural beauties, but in the same time it is the main source of drinking water for entire Sulaimaniyah city.

The general water demands of the Sulaimaniyah city is rapidly increasing along with its population and industrial growth. The number of inhabitants has increased from 20000 in 1930 to 53000 in 1960, 200000 in 1980 and 700000 in 2005. The total water demand of the city reaches 200000 m^3 per day; 70% of this amount is covered by the spring water, from mid November till June, while the pumped surface water from Dokan reservoir, some 50 Km far from the city is ensuring the supply for the rest of the year.

The water of Sarchinar spring drains out not only from the main discharge point (Fig.1), but also from a cluster of small springs. During the high water period, the system overflow is clearly outlined by these temporary springs located 900 m upstream of the main outlet. According to Maulood and Hinton (1978) there are 16 such small springs.

PREVIOUS STUDIES

The Sarchinar spring was the object of several studies and investigations, but mostly related to some specific aspects of its utilization. Therefore, still no complete survey of this important spring is undertaken.

Anon (1957) described Sarchinar spring as "one of the larger springs, supplies municipal water for the 43000 inhabitants of Sulaimaniyah. In June 1957, the yield of the spring was calculated to be 56000 US gallons per minute. Water is also diverted from this spring and used extensively for irrigation".

Cwiertniewski (1961) reported that groundwater, which drains from Sarchinar spring “is flowing through open solution channels”.

El-Yossif and Al-Najim (1977) published a paper on the hydrological and chemical properties of the spring.

Maulood and Hinton (1978) studied the ecology of Sarchinar spring.

Al-Rawi *et al*. (1990) performed geoelectrical and hydrogeological survey in wider area.

Al-Manmi (2002) conducted an environmental and hydrological study of groundwater in Sulaimaniyah area that also included Sarchinar spring.

Mohammed (2004) studied the ecology and aquatic life of the spring water.

Stevanovic and Iurkiewicz (2004a) completed hydrogeological study of the entire region. The Sarchinar spring flow regime and its importance were also emphasized in their work.

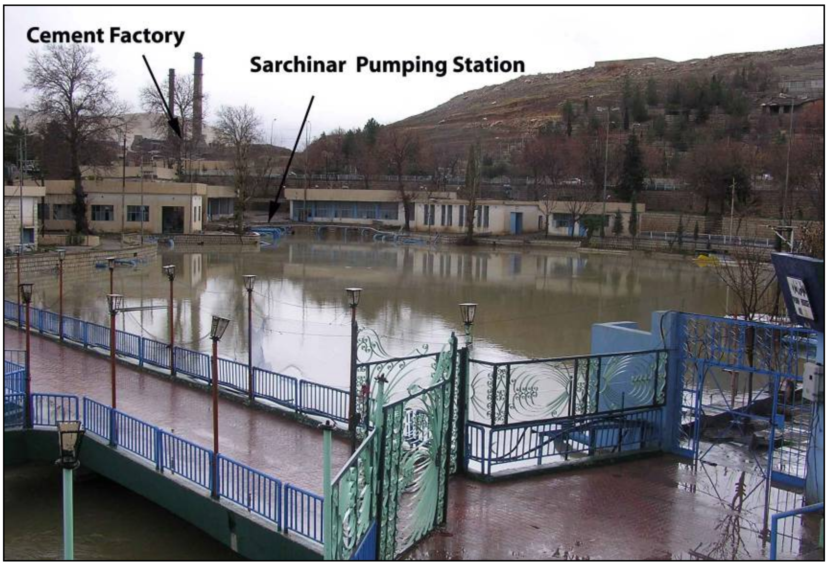

Fig.1: Pumping station at Sarchinar spring in Sulaimaniyah city

GEOLOGICAL SETTING OF THE CATCHMENT AREA

The northern part of Iraq (including Sulaimaniyah Governorate), as a part of Western Zagros Fold – Thrust Belt is represented by high mountains; most of them are more than 2000 m (a.s.l.) (Eastern Taurides and Western Zagros). From north to south the three major tectonic zones are: Thrust Zone, High Folded Zone and Low Folded Zone (Buday, 1980 and Buday and Jassim, 1987). The Sarchinar catchment area belongs to the High Folded Zone with dominant presence of carbonate and clastic rocks of Cretaceous age and rare Gurassic rocks.

Balambo, Sarmord and Qamchuqa formations date from the late phase of Early Cretaceous (Aptian – Albian), with thick layers (often massive) of dominantly carbonate (limestones and dolomitized limestones). Lower and the middle parts of Late Cretaceous rocks also consist of carbonates (Kometan and Dokan formations), or "impure" carbonates (Shiranish Formation) and clastic rocks (Tanjero Formation).

The total thickness of each formation indicated is between (100 – 500) m, but is largely variable and is rather reduced (upper part is often eroded). Great inclination of layers, sometimes sub-vertical slope, which is descending generally to the SW direction, is the result of intensive orogenic movements (Stevanovic and Markovic, 2003). Sarchinar groundwater basin includes part of Pira Magroon and Azmir anticlines with several smaller modulated folds, all are separated by the narrow syncline of Chaq Chaq valley (Figs.2, 3, 4 and 5).

The Sarchinar spring and Chaq Chaq valley are located within the northern part of larger watershed of Tanjero stream, which finally collect all surface and subsurface water to the Darbandi Khan reservoir. The Sarchinar basin alone extends for a distance of nearly 25 Km to the north and about 3 Km to the south from the spring site. Its width, between bordering divides is about 8 Km, whereas total catchment area is assessed to be approximately 200 Km^2.

The spring is located in the lowest and last elevation of the southeastern plunge of Pira Magroon anticline, where the Kometan Formation is exposed (Figs.3, 4 and 5). It is marking the contact between karstified and fractured limestone of Kometan Formation with marls of Shiranish Formation (Late Cretaceous). The late unit is acting as impervious barrier and directs water to ascenditional flow out. Therefore, the location of the spring is controlled by both, morphology and stratigraphy of the area.

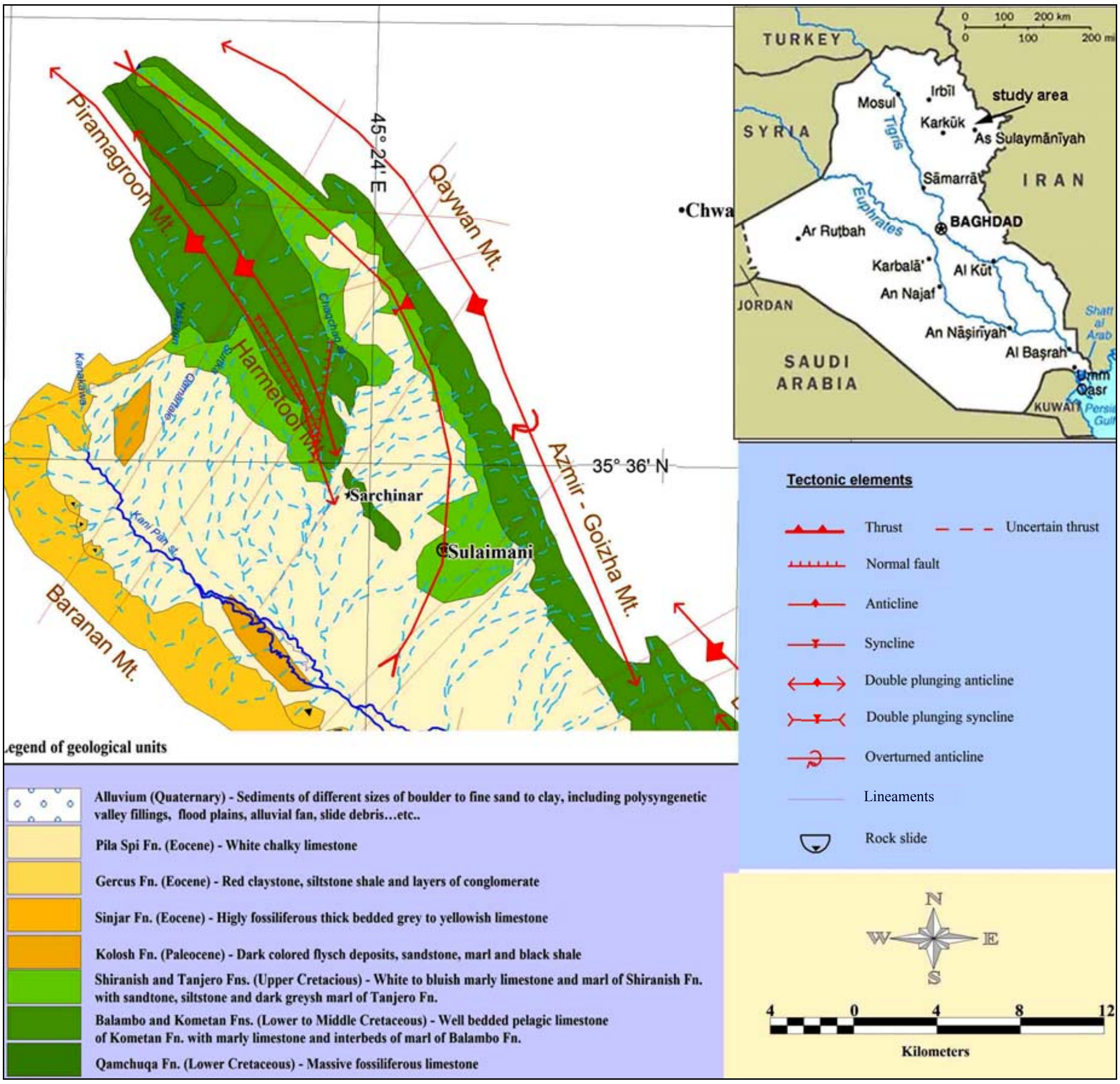

Fig.2: Geological map of a part of Sharazoor – Piramagroon Basin along which the catchment area of Sarchinar spring is shown (after Ali, 2007)

HYDROGEOLOGICAL PATTERN

The recharge areas of two parallel anticlines (Pira Magroon and Azmir) consist of limestones of Kometan and Qamchuqa formations, and the upper part of Balambo Formation. Kometan Formation consists of well-bedded and fine crystalline limestone, which has the thickness of 120 m. In Qamchuqa Formation, massive dolomitic limestone is prevailing, with a thickness that can reach some 600 m. The formation crops out along limbs and crest of the anticlines that surround the Chaq Chaq valley (Fig.3). The upper part of Balambo Formation consists of about 200 m of yellowish white well-bedded limestone. This part is very similar to Kometan; the only difference is the stratigraphic position and higher content of marl; component. This unique karstic aquifer also called as “Bekhme” by Stevanovic and Iurkiewicz, (2004a); is characterized by great thickness and large surface extension. It is highly fissured, well-karstified with many channels and caverns that were registered on the surface (Karim *et al*., 2003) or during the drilling.

Not all exposed rocks in the Chaq Chaq valley take part in recharging of Sarchinar aquifer. More than half of the valley surface is covered by impervious Tanjero and Shiranish formations. Tanjero Formation is characterized by rhythmic alternation (succession) of thin beds of sandstone with very thin interbeds of calcareous shale. These types of lithologies act as thick impervious succession, except where they are intensely deformed, then may form shallow and local aquifer (or aquitard). The sandstone and shale beds are completely barren of porosity but some recently drilled shallow wells showed that the sandstone succession can be a local aquifer when is deformed (fractured and jointed). Shiranish Formation consists of thick succession of marl and marly limestone. These two formations thus have very low infiltration coefficients, a large portion of runoff water leave the Chaq Chaq valley without recharging Sarchinar springs, particularly during winter months. During spring and summer seasons, before Chaq Chaq valley is completely dried out, the lower velocity causes increase of seepage towards karstic aquifer in both vertical and lateral contacts.

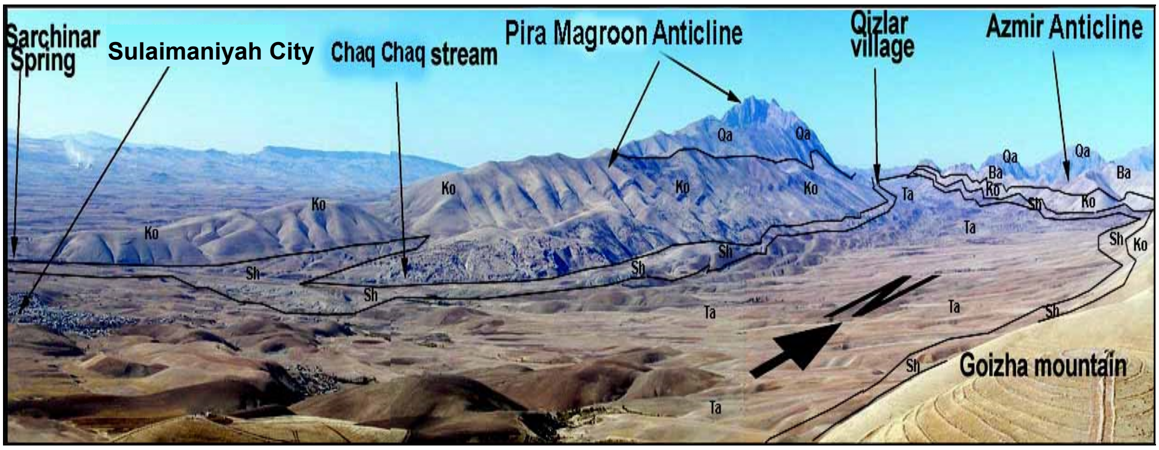

Fig.3: General view of Chaq Chaq valley, showing the exposed Cretaceous formations: Ta:Tanjero, Sh:Shiranish, Ko: Kometan, Ba: Balambo, Qa: Qamchuqa

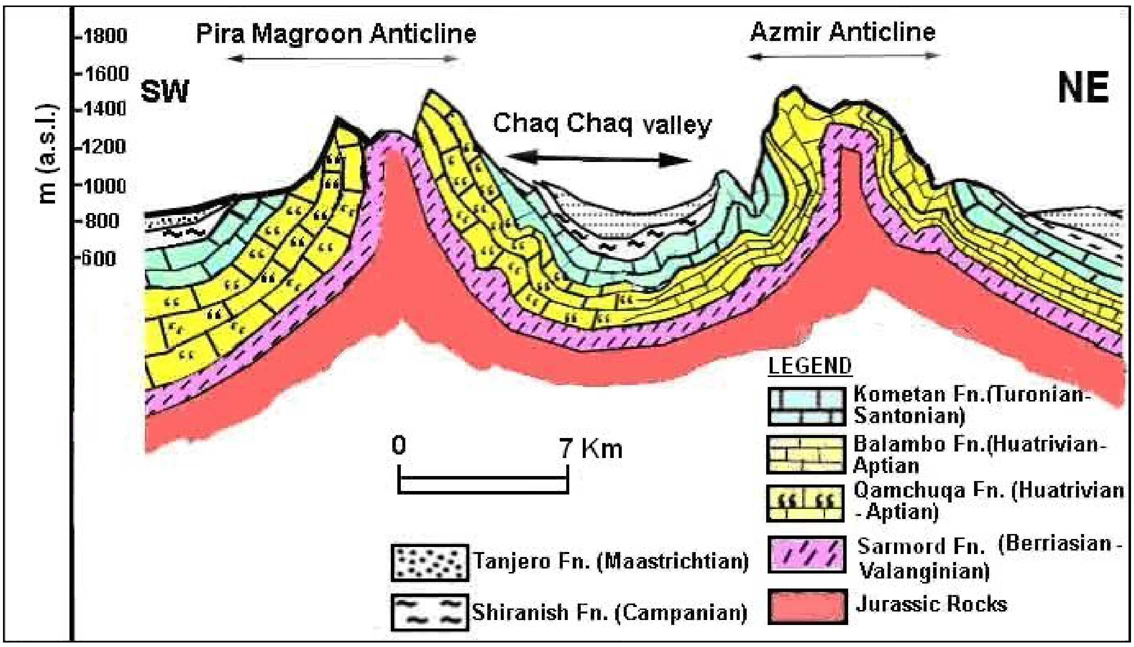

Fig.4: Transversal geological cross section across Chaq Chaq valley (syncline)

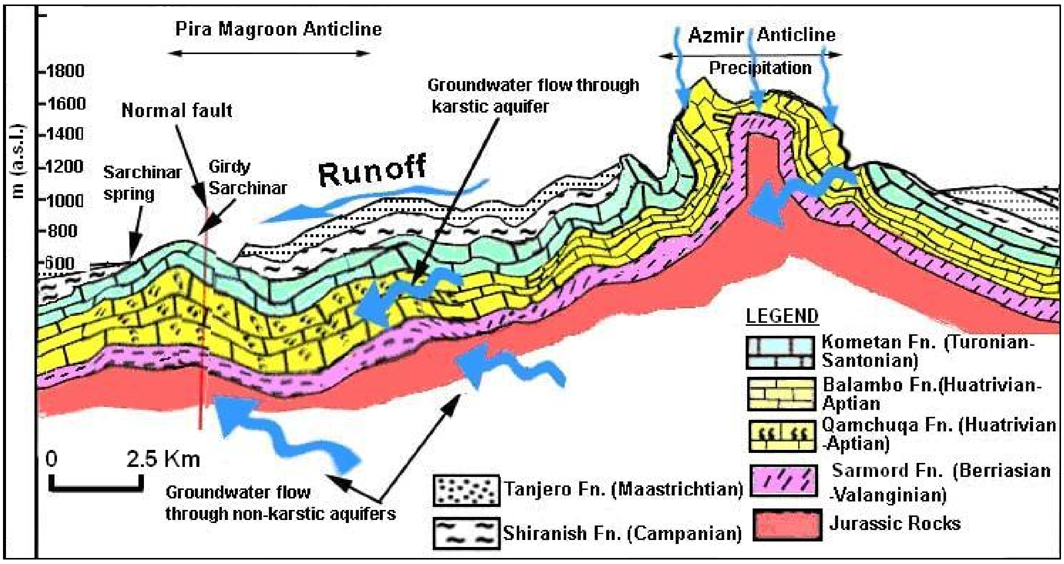

Fig.5: Geological cross section crossing Azmir anticline and the spring site

STRUCTURAL CONTROL OF THE SPRING

The infiltrated water within karstic aquifer from the crest and upper parts of both limbs of Pira Magroon anticline is flowing towards lower part of both southwestern and northeastern limbs of the anticline and then became diverted toward the plunge where the Sarchinar spring is located. There is an important reverse high angle fault, named North Sarchinar Fault striking NNW – SSE, which crosses the Chaq Chaq valley nearly 1.5 Km to the north of the spring. A good amount of water enters this fault zone and infiltrates vertically downward (Al-Rawi *et al*., 1990).

By mean of North Sarchinar Fault, the terminal part of the southeastern plunge (locally called Girdy Sarchinar) (Fig.5) is abruptly subsided. The role of the fault was even more significant during past, before enhancement of the flow direction by karstification. Slightly south of the Sarchinar spring there is a major transverse fault, which has been named as Sarchinar Tear Fault (Al-Rawi *et al*., 1990). The southern block of this fault has relatively moved about 20 m downward and 200 m eastward. The fault actually consists of a number of parallel fractures. Due to this fault, the whole area (due south) has been tilted towards NW, forming a topographic saddle (Al-Rawi *et al*., 1990).

GROUNDWATER BUDGET

The recharge area is characterized by mean annual precipitation of about 700 mm in the foothills, but it may even reach about 1000 mm in higher altitude areas. The maximum rainfall is during the winter months when the snow covers higher peaks. The annual rainfall in north Iraq is not much less than the annual rainfall in most of Europe, but the difference is in its distribution. Almost by a rule, there is no rainfall between June and September. Taking the average rainfall for the whole basin area is about 800 mm per year and the basin surface is of 200 Km^2, the total recharge potential is 160 x 10^6 m^3 per annum (Al-Rawi *et al.*, 1990). There are a number of longitudinal and transversal faults and fracture zones, which facilitate the percolation of water from the surface into the subsurface. The basin configuration is also quite favorable (wide valley and gentle slopes) for higher percentages of filtration surface water into the ground water, within the karstic outcrops. It is assumed that all these factors may allow more than 55% of the annual rainfall to percolate down into the ground. Thus, the annual recharge of the groundwater basin should be around 80 x 10^6 m^3.

KARSTIFICATION

During the long geological history of the Tertiary of Northern Iraq, especially in the Mesozoic and Tertiary periods, a lot of soluble rocks like limestone, dolomite and evaporite were deposited. These rocks enabled the development of strong karstification and formation of both surface and underground karstic morphology.

The alpine folding and uplifting of mountains built-up of carbonate rocks are continuous until the present, causing stronger penetration of surface water to underground. This was reinforced by numerous fissures, joints and fault surfaces, and deepening the basis of karstification. Two different levels of karst are formed in different phases and could be connected in some places, offering a false picture of the unique process of karstification, (Stevanovic and Markovic, 2003).

Carbonate rocks, generally show non-homogeneity with prevailing presence of limestone, but also with insoluble varieties such as interstratified clays. In Balambo Formation or in marly limestone in Shiranish Formation, uplifting of carbonate beds and their intensive folding and faulting, repeated in several phases, caused the complex systems of faults and fractures as privileged ways for the water circulation (Stevanovic and Iurkiewicz, 2004b).

Surface karstic small forms, with dimensions from centimeter to decimeter, occur practically in the whole limestone area. Compared with other karstic Euro-Asian mountainous ranges formed during the Alpine orogenic cycle (Alpides, Dinarides, Helenides, Taurides), typical larger surface forms, such as sinkholes or dolines, are not as frequent in this region. Some large depressions resemble the polje forms, but they are always open in the direction of the main drainage stream. Even if they are formed by karstic process, they have been strongly modified by surface fluvial process (Stevanovic and Markovic, 2003).

In the study area, limestone rocks of Qamchuqa Formation responded more to karstification processes than the other Cretaceous rocks, and many dry caves with small diameters, from less than one meter to more than 3 m, of previous groundwater tables now exist in these rocks. Due to relatively thin bedding layers of Kometan Formation no opportunity for karstification process occurred, but lot of relatively large shallow subsurface cavities and open channels have been detected 200 m upstream of Sarchinar spring by Al-Rawi *et al.* (1990), beside similar cavities found during drilling wells in these rocks.

DISCHARGE REGIME AND TIME SERIES ANALYSIS

The karstic properties can be inferred from the discharge fluctuation of the spring. The spring discharge increases several times after each storm with more than 30 mm of rainfall and is rapidly decreased after few days.

According to analysis of data from the pumping station that supply the Sulaimaniyah city, during the recession periods of 1999 and 2000, the minimal discharge of the system was evaluated to be around 600 l/sec. Application of the recession coefficient method was attempted for the spring and based on the spring hydrograph was recorded during April 1999 – March 2000 (Fig.6). By using the Mailet recession curve, two recession coefficients were obtained:

- $\alpha 1 = 0.0068$ (discharge reduced from 1.36 to 0.94 m^3/sec within 36 days), and
- $\alpha 2 = 0.00018$ (discharge additionally reduced to 0.67 m^3/sec within 122 days)

Considering that the second recession coefficient ($\alpha 2$) characterizes a very slow drainage through, the well-karstified and rich aquifer of Pira Magroon and Azmir Mountains; it was inferred that complete exhausting of dynamic resources of Sarchinar reservoir would theoretically require a period of almost ten years of continuous discharge without any additional recharge (Stevanovic and Iurkiewicz, 2004b).

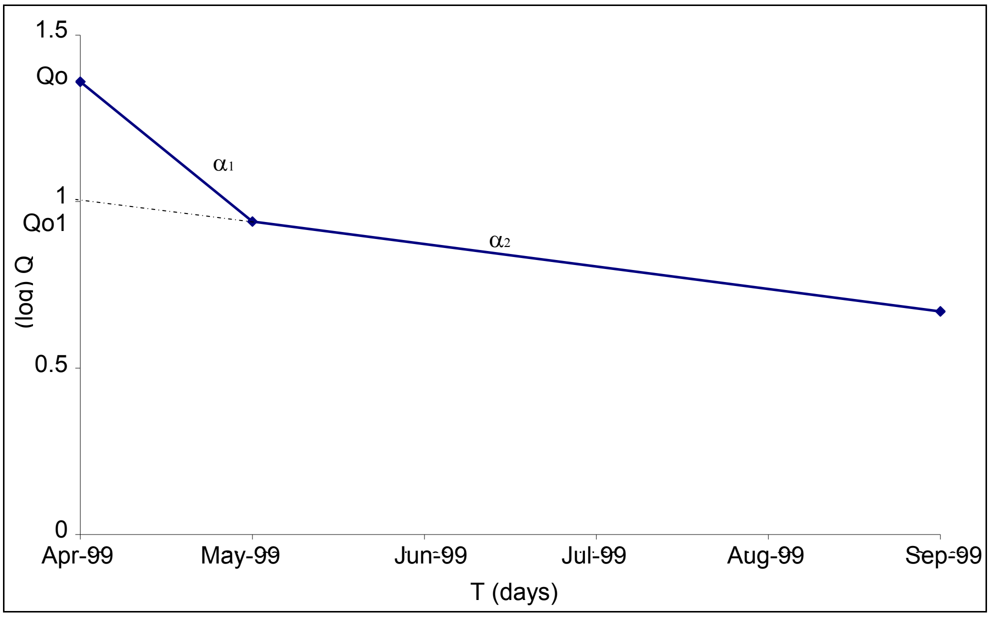

Fig.6: Sarchinar spring discharge during recession period of 1999

After the short drought cycle that affected the entire region, during the years 2001 and 2002 the following spring discharges were recorded (Table 1):

Table 1: Characteristic data recorded of Sarchinar spring

Q max.	Q min. (in 2002)	Q av.	Q max./ Q min. (in 2001 only)
(l/sec)			
7130	861	3131	12.84

The system reacts to rainfall events with a delay of (2 – 3) days representing the minimum travel time for the recharging inputs (Fig.7). Meanwhile, a slow reaction could be observed after approximately one month (rainfall at the beginning of May transferred as output at the beginning of June).

The analysis of spring hydrographs may provide valuable indirect information on the structure of the karst hydrogeological system (Bonacci 1993; Krešić, 1997 and Larocque *et al.*, 1998). For this purpose the method of implementing systematic (time series) analyses was developed (Mangin, 1984).

As an initial step for characterization of a karst aquifer, the results of autocorrelation, spectral density and cross-correlation should be taken into consideration (Jemcov, 2006). According to such analysis applied in case of Sarchinar hydrogram for the year 2003, auto-correlogram of discharge rates of the spring exceeds the confidence limits for approximately 85 days (Fig.8). This implies that aquifer storage is significant and that it releases water gradually. Also the very slow decline of the auto-correlogram shows a relatively stable discharge regime, conditioned by the limited dimensions of the karst channel, which also confirmed earlier made statement of large groundwater reserves (for drought year of 1999).

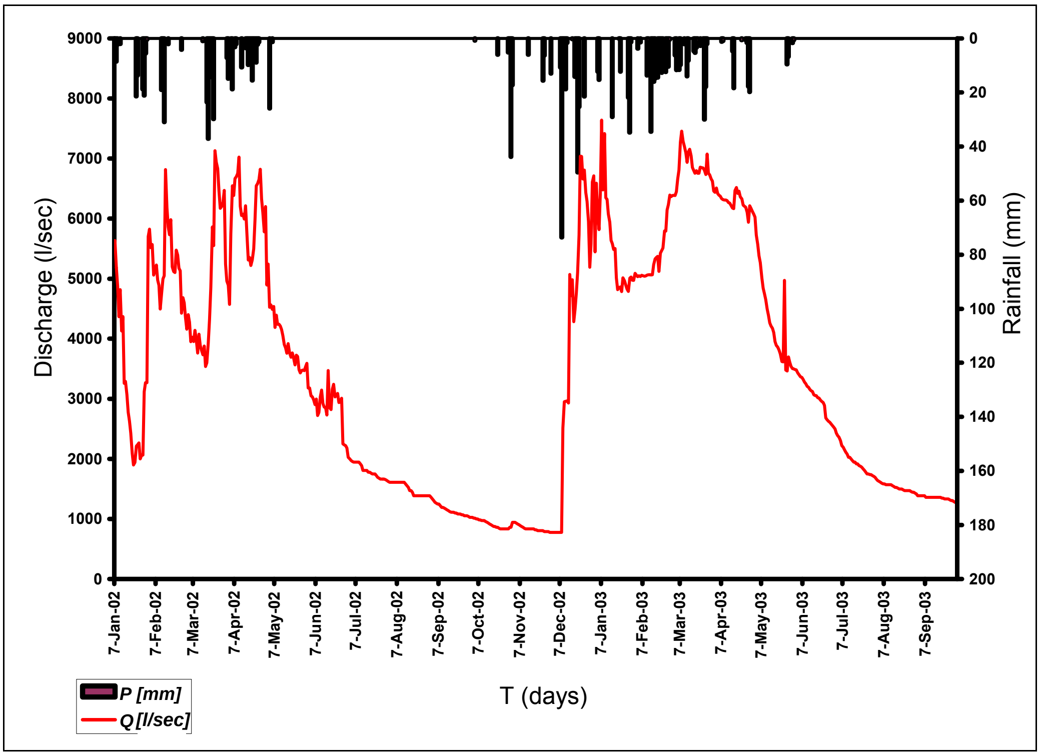

Fig.7: Correlation chart: rainfall (Sulaimaniyah), Sarchinar spring

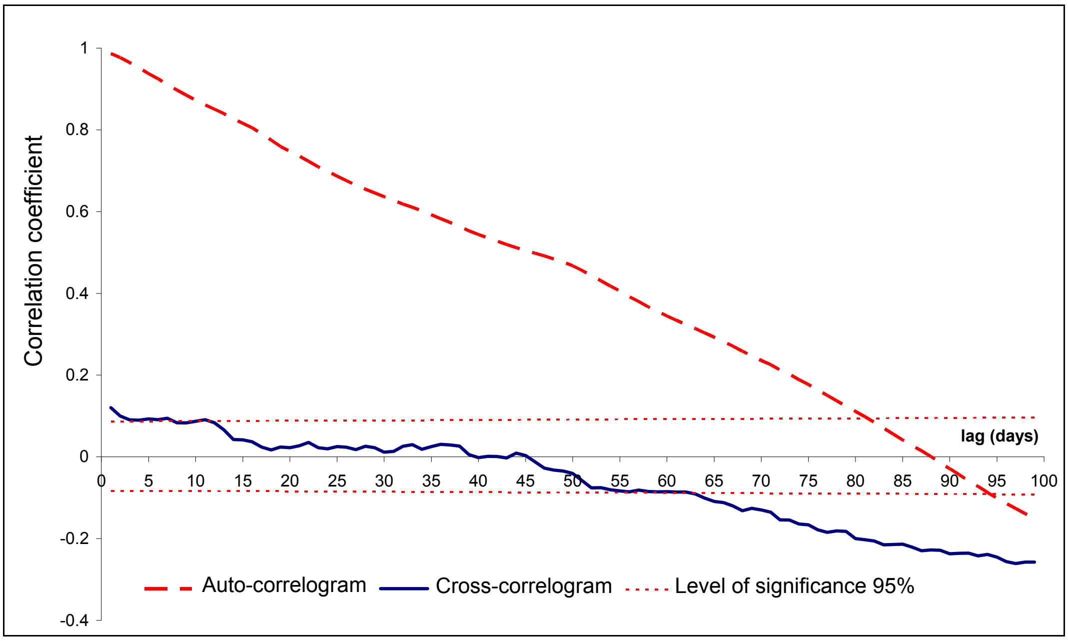

Fig.8: Auto-correlogram and Cross-correlogram of Sarchinar spring

The spectral density function of the spring discharges show high peaks at a low frequency of 0.003165 (above 300 days), which confirms the presence of an annual cycle (Fig.9). Considerable peaks at the frequencies (from about 120 – 90 days) show seasonal cycle of spring. Beside peaks at the middle frequencies (from about 40 days), which show relatively low densities, at high frequencies even the low density does not exist. This analysis confirms that Sarchinar spring is characterized by seasonal recharge and discharge cyclicity.

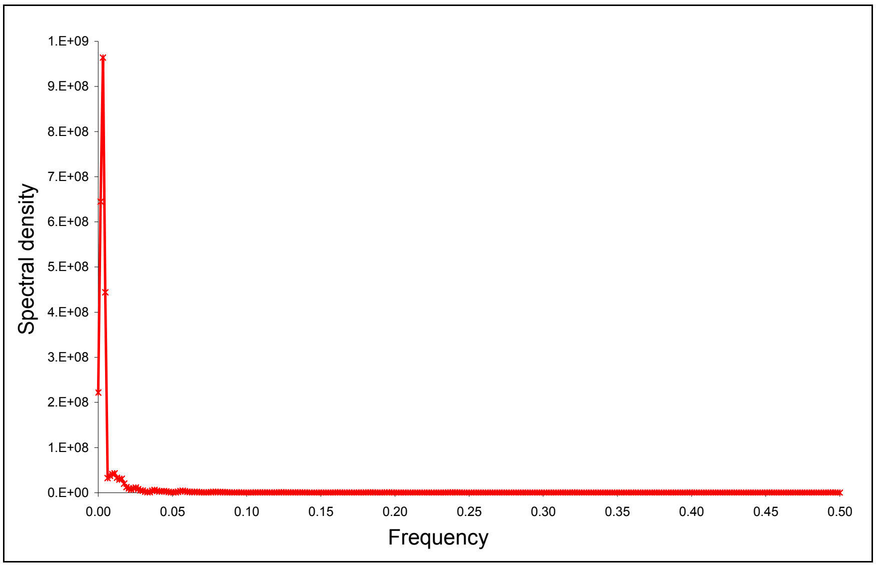

Fig.9: Simple spectral analysis of Sarchinar spring discharge

Cross-correlograms for spring flow and precipitation shows a very minor level of significance from (3 – 11) days, but after that is insignificant. Low cross-correlation values show that the influence of infiltration is significantly attenuated by the karst hydrogeological system.

The statistical test of rainfall-discharge data for four days lag time shows a high correlation and response between rainfall and discharge (Fig.10). Accordingly, very minor differences were found between observed and simulated discharges.

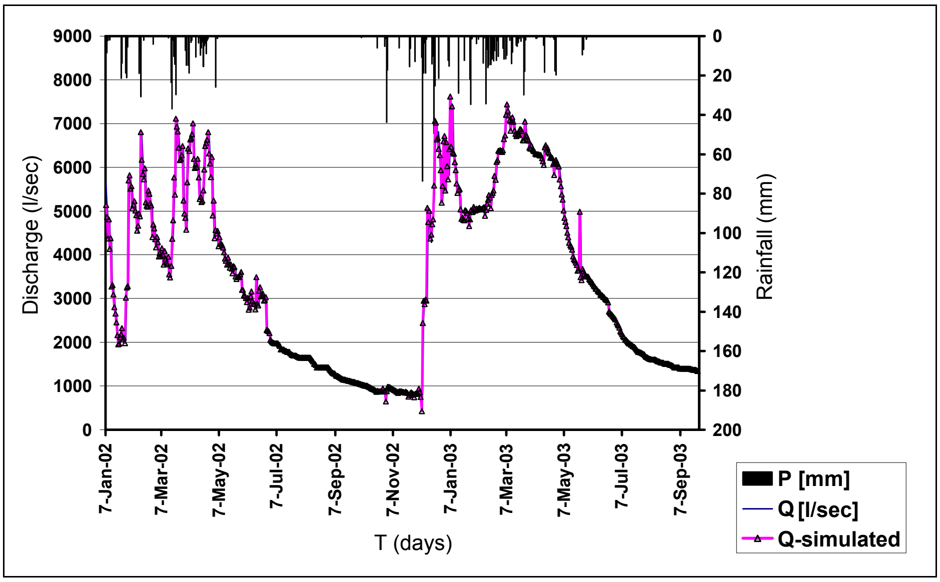

Fig.10: Diagram of observed and simulated discharges of Sarchinar spring

Altogether, the analysis shows large storage capacity for the Sarchinar aquifer. Water is stored within this karst hydrogeological system during the recharge period and is later slowly released during the dry season. Dynamic resources are the consequence of small fissures and matrix porosity (slow subsequent water release following de-saturation of larger fractures), as well as the large subsurface reservoir that extends from Pira Magroon anticline towards the outlet.

ENVIRONMENTAL IMPACT

The Sarchinar spring is located in NW suburban area. Very close to the spring, at a distance of some 200 m there is a cement factory (which auspiciously is now closed and planned to be abandoned) and a small quarry, which both have had significant impact on the water quality and disturb the environment.

The Sarchinar spring is also suffering from several other problems: The first one is the continuously spread of urbanization toward the recharge area in addition to increase population of the densely distributed villages in the upstream of Chaq Chaq valley. The second source of pollution was attributed to the newly built dam of 13 m height. This dam was constructed at 1 Km to the north of the spring on a temporary stream (wadi) (Fig.11). In spite that hydraulic connection has never been confirmed by tracing tests, it is certain that surface water is percolating near the spring after leaving impervious rocks of Tanjero and Shiransh formations, through aforementioned large faults and numerous fractures and caverns within Kometan karstic aquifer.

The Chaq Chaq Dam was built by support of NGO in late 2002, but without feasibility study or previous research. Furthermore, the dam design and construction was inadequate to properly maintain the water storage, thus the first serious flood happened in 2006 caused the collapse of the dam (Fig.12).

The idea to build a dam with a reservoir in Chaq Chaq valley has no significant importance with hydrogeology or controlling of aquifer. The primary aim was to store temporary stream flow. But, shallow reservoir in an area such as Iraqi Kurdistan where daily evaporation rate during summer reaches 1.5 cm/day is not sounding favorable. However, such kind of dam in narrow spring outlet area theoretically could have some positive implications concerning reduction of water velocity and more extended aquifer recharge throughout the year. To confirm such statement, some evidences of more stable discharge were identified on the spring hydrogram for the year 2003 comparing the previous ones.

There are two other facts that confirm deeper circulation within karstic aquifer: **First,** relatively constant temperature of the spring water throughout the year (±17° C), while air temperature varies from less than 0° C to more than 40° C. **Second,** rarely recorded increased turbidity values of the spring, even after heavy rainfalls.

The blasting processes which had been performing for more than 40 years for quarrying limestone to supply the cement factory, located directly 200 m north of the spring, on the neighboring hill has had a great impact in the widening of the existing joints and fractures and even creating of new ones. These fractures that have direct connection with surface are extended as open channels and even caves to the spring location (Al-Rawi *et al.*, 1990).

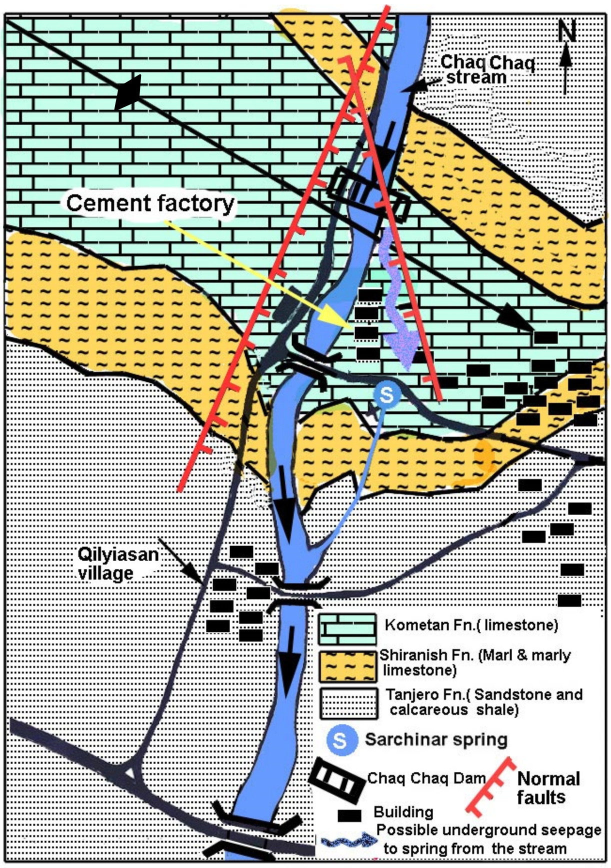

Fig.11: Geological sketch map of the mouth of Chaq Chaq valley (syncline), showing the locations of Sarchinar spring and recently constructed earth dam

Fig.12: Broken dam's wing at the right bank of Chaq Chaq valley

INSTEAD CONCLUSION TOWARDS AQUIFER CONTROL

Sarchinar spring is of essential importance for future development of Sulaimaniyah city. Its ascensional flow, large catchment and huge groundwater resources provide an opportunity for better utilization and control of karstic aquifer. The precondition is systematic hydrogeological research that should include geophysics, drilling, tracing and permeability tests, and several other methods in order to determine most suitable tapping structures and methods of possible artificial control of the discharge.

During late 2005, conducted hydrochemical and biological analysis (performed in Sulaimaniyah University Laboratories) proved that the spring water is still meeting WHO and Iraqi standards. However, permanent monitoring and preventive measures against pollution are order of the day, concerning existing open karstic system, narrow highly populated area and several potential polluters.

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